A REVIEW OF IFC STANDARDIZATION – INTEROPERABILITY THROUGH COMPLEMENTARY DEVELOPMENT APPROACHES

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ABSTRACT

The Industry Foundation Classes (IFC) data model has been in development by an industry consortium since 1994; during this time the industry context, standardization organization, resource availability, and technology development have exposed the standardization process to a dynamic environment. While the overarching mission of IFC standardization has always been to provide interoperability between AEC/FM software applications and actors, both the goals and the views on how to best achieve those goals have changed throghout the years. Despite the fact that IFC has enjoyed sustained professional and scholarly interest throughout its development, reflective socio-technical studies on the subject are largely non-existent. This study reviews the major shifts in the development process of the IFC standard from its origins in the early 1990s up to 2011, splitting the timeline into four distinct phases. A finding of the review is that the IFC standardization process has utilized complementary minimalist and structuralist approaches for different phases of the standardization process - balancing exhaustive structuralism and implementable minimalism. The concepts behind Model View Definitions (MVD), Information Delivery Manuals (IDM), and the International Framework for Dictionaries (IFD) were not documented from the start and only became relevant as standardization progressed, with each of the components contributing minimalism to a structurally constructed data model.

Keywords: IFC, interoperability, standardization, BIM, review

1 INTRODUCTION

Development of the Industry Foundation Classes (IFC) standard was formally initiated in 1994, and resources have been poured into the effort ever since without interoperability reaching the level of functionality or industry uptake as originally envisioned. While certified implementations of major IFC releases have been present in leading building information modeling (BIM) software since early 2000, real-world use of the format as an enabler of interoperability between project actors has still remained low (Kiviniemi et al. 2008; Young et al. 2007). The exchange of BIM files is dominated by proprietary solutions - this despite the fact that industry started to work on specifications for open interoperability relatively early relative to the technological maturity of BIM software. IFC-supported model-based construction is something that has the potential to transform the core fundaments of construction processes. The potential for productivity increase is substantial: open interoperability for building information modeling would enable the seamless flow of design, production and maintenance information, reducing redundancy and increasing efficiency throughout the whole lifecycle of the building. As such the IFC effort can be considered one of the most ambitious IT standardization efforts in any industry.

2 RESEARCH AIM AND METHODOLOGY

The majority of the research related to the IFC standard can coarsely be categorized as applied science; documenting implementations of the standard in software, technical performance evaluations, and functionality or scope extensions to the baseline standard being among the most common. By drawing on existing literature, documentation, and research this paper suggests looking at the socio-technical process of IFC standardization in itself instead of limiting focus to the output of the process. In addition to an overview of the development process as a whole, of particular interest in this paper are the changes in both the standard and the organization behind it. The concepts of 'minimalist' and 'structuralist' development methodologies are used as analytical lenses for identifying and contrasting the changes in development methodologies that have happened over time,. The following definitions are used for describing the two general approaches (Behrman 2002:3):

"The minimalist approach values simple standards and rapid adoption by the user community. It is a bottom-up approach in which standards start small. The development process places heavy emphasis on experimentation, testing, and iterative improvement of proposed standards in applications before adoption. Once such standards are adopted and gain acceptance, they are further developed as needed" [...] "The structuralist approach values comprehensive and complete standards. It is a top-down approach. The development process starts with a high-level model and then proceeds with the elaboration of more and more detail. The process is often daunting and time-consuming."

Behrman (2002) described and compared the IFC standardization process to efforts in other areas of IT standardization, arriving at the conclusion that IFC has largely followed a structuralist approach. Behrman noted that IFC has had problems gaining functional software implementations, blaming it largely on the lack of inclusion of software vendors in the standardization process. The structuralist approach, the low resources, the lack of industry involvement and commitment, and the EXPRESS modeling language were pointed out as being main obstacles for successful standardization. As a conclusion to the analysis of the standardization cases, Behrman argued heavily for the use of bottom-up minimalist standardization methodology in favor of a top-down structuralist one. In addition to providing a chronological extension to the earlier study, this study also re-evaluates the earlier findings in light of new information.

3 REVIEW OF IFC STANDARDIZATION

3.1 -1994: Stepping out

In 1984 the TC184/SC4 subcommittee of ISO evaluated that no existing product information format could on its own be extended to serve the needs for an open computer modeling standard for multiple industrial and manufacturing industries; it was at that point when development of STEP (Standard for the Exchange of Product model data) was formally initiated. The AEC/FM industry was just one among the several industries included for standardization within STEP. The STEP specification formalized a long line of development of national and industry consortia standards development (Bloor & Owen, 1995: Kemmerer 1999). SC4 recognized that robust data modeling was central to support the complexity of STEP, and after some evaluation existing modeling languages were deemed incomplete or unsuitable for the requirements of STEP. Thus began an effort to develop a language that later became known as EXPRESS (Kemmerer 1999). The EXPRESS information modeling language was initially developed in conjunction with STEP for defining the STEP data models and the standard itself. Relationships, attributes, constraints, and inheritance are core concepts of EXPRESS (Schenck & Wilson 1994). Before the need for separate Application Protocols for different industries became apparent there was an attempt to integrate the information models from different disciplines. This was problematic and progressed slowly as the existing models were on different levels of abstraction (Kemmerer 1999). In December 1994 the initial release of STEP became an international standard - ISO10303:1994, Industrial Automation Systems and Integration - Product data representation and exchange (ISO.org). Considering the previously presented definitions for standardization methodology, the STEP effort is a textbook example of a structuralist effort, as also pointed out by Behrman (2002).

While the STEP ideology of having common universal resources at the core of a comprehensive standard intended to cover a diverse range of industries was an attractive prospect, reducing redundant standardization work and enabling easier future cross-industry collaboration, the motivation to start a separate standardization effort grew among actors in the AEC/FM industry. The ISO developed STEP standard, which had been undergoing standardization for 10 years since 1984, was considered too slow and unresponsive to meet the demands of the AEC/FM industry within the near future (Tolman, 1999).

3.2 1994-1999: From initiation to IFC 2.0

In August 1994, 12 US based industry and software companies joined together examining the possibility of developing an open standard for increased interoperability for emerging building information modeling software. After putting together initial prototypes showcasing the potential, in September of 1995 the IAI (Industry Alliance for Interoperability, later changed to International Alliance for Interoperability in 1996) was formally founded and the consortia opened up for other companies to join (IAI 1999c). IAI had established 7 chapters in 1996, each a separate organization representing an international region: French Speaking, German Speaking, Japan, Nordic, North America, Singapore, and the UK Chapter (IAI, 1999c). The IAI stated its vision as *"To enable software interoperability in the AEC/FM industry"*, with the mission "*To define, promote and publish a specification for sharing data throughout the project life cycle, globally, across disciplines and across technical applications*" (IAI 1999c:3) Using existing parts from the ISO STEP standard, most notably the EXPRESS modeling language and STEP file format, technical development was not started from an empty slate. Thus work started on design of the standard, the IFC information model, which purpose was to contain descriptions of core AEC/FM industry objects and concepts. IFC 1.0 was published in January 1997, with scope being primarily focused on the architectural part of the building model. This first release was only used for prototypes in order to get some initial experiences for using the format and increase stability for IFC 1.5 (Liebich 2010). Implementation in BIM software did not happen until July 1998, with several commercial modeling suites supporting IFC 1.5.1 (IAI-international.org). At this point the objective of the IAI was to issue one major release of the IFC information model annually (1999c).

In 1997, a liaison agreement and a 'Memorandum of Understanding between ISO TC184/SC4 and IAI' was issued to strengthen the knowledge sharing between the two organizations and standardization efforts (IAI 1999c:20). The difference between the two efforts remained the forum of standardization and core mission scope; formulated succinctly in a paper from that time as "*STEP must take as much time as necessary; the IAI must act quickly*" (Baznajac & Crawley, 1997:209). In a review of the product modeling standardization efforts of the AEC/FM industry at the time, both the STEP and IFC standardization processes were given fairly pessimistic outlooks. STEP was evaluated as being fragmented and burdened by democracy, having no real drive behind it, and IFC for being weakly supported by the industry actors and too low on resources to make substantial progress (Tolman 1999).

Development of IFC 2.0 started in December 1996 and the final release was delivered largely on schedule 29 months later, in April 1999. The scope for IFC 2.0 was primarily to incorporate schemas for building services, cost estimation, and construction planning (Liebich 2010). The IAI hard costs for the release were very low at under 400 000 USD, however, estimated contributor labor effort being in the ballpark of 2.5 million USD (Kiviniemi 2006). These numbers showcase the reliance on contributed and indirectly funded resources in the standardization. To narrow the gap between the publication of the standard, and implementing it in software, the Building Lifecycle Interoperable Software Group (BLIS) group was founded in 1999 to accelerate and coordinate implementation efforts (BLIS-project.org). This was a separate organization from the IAI with its own optional membership. The goal was to give software vendors a possibility to collaborate and get an early start on developing implementations (Karstila & Serén 2001). A vision for BLIS was also to develop specific BLIS use cases of the IFC model, i.e. restricted but well-supported subsets of information to be exchanged in a specific workflow. This was a change from the past towards a minimalist approach to interoperability, in the past implementers had largely been dealing with the IFC information model without much in the way of common guidelines.

3.3 2000-2005: Towards ISO PAS and IFC 2x

This time period marked several important shifts in the standardization process. The initial enthusiasm for the standardization effort was put up against some harsh realities: IFC 1.0, 1.5 and 2.0 were receiving lukewarm reception from the industry, IFC usability in real world projects was generally deemed unreliable. Coupled with dwindling resources and lack of long-term plans for future development one can easily identify this as one of the major low-points in the process, when changes had to be made in order to maintain momentum and industry relevance. Prior to the year 2000, road maps for future development were largely absent, partly due to the lack of a common perspective concerning the content and purpose of the standard. In an excerpt from meeting minutes of the Nordic IAI Chapter Board Meeting in October 2000 (p.2) the general atmosphere of the time is conveyed effectively: "*The main problem is lack of international resources. Also the lack of participation of some chapters on international level is causing problems in decision making process, because it is very difficult to get the majority*.".

Focus of the work within IAI was initially oriented towards specification development, leaving it to the industry to figure out feasible use-cases and implementations of the produced specification into software. Considering that development of the standard was a huge effort in itself, it is understandable that the limited consortia resources did not make it possible to establish robust in-house implementation support processes early on. No one was paid for supporting or monitoring implementations; general implementation and certification meetings were the main and only activities (Kiviniemi 2006). An effect of the liberal approach to implementations presented problems for setting up a unified robust certification process. Around the release of IFC 1.0 and 1.5 there was an urgent push for getting IFC certified products out on the marketplace, which combined with the insufficient resources, lead to setting up very simple certification tests. While the official certification guide is not a public document and was only available to IAI members, nor would it be possible to go into to much detail in this context, the central parts of the process are described in other publications, e.g. IAI (2000), Karstila Serén (2001), Steinmann (2010). Implementation quality with certified products was not sufficient for reliable use between software applications in real projects. Despite the problems with fundamental interoperability, marketing of future releases of the standard was done with emphasis on new features and domains covered by the standard, despite the fact that only a small fraction of the existing features had been implemented in the commercial software. These problems together contributed towards the still persistent notion that IFC interoperability as a whole is not usable.

Initially the intention was to keep IFC accessible only to members of IAI chapters it was not until the IAI summit in Munich October 1999 where the notion of an openly available IFC standard and documentation were brought up for formal discussion within the consortia. The open publishing and free use of the IFC standard were formally approved during the next international IAI summit in Melbourne, February 2000 (Nordic IAI Chapter Board Meeting 3/2000). In addition opening up the IFC specification, the Melbourne meeting was an important turning point in the standardization process and described in the meeting minutes as giving *"...new hope for the future of IAI"* (Nordic IAI Chapter Board Meeting 3/2000). Not only did the consortia decide to open up the standard to be implemented by anyone for free, and adopt a more transparent standardization process, but at the same time also initiated the ISO PAS (Publicly Available Specification) process to get IFC on the road to becoming an ISO published international standard. In order to increase the legitimacy of the standard it was made a high priority within the consortia to get ISO to publish the standard (IAI Nordic Meeting Minutes). During this time the consortia also got increasingly global with 5 new chapters having joined the consortia between 1997 and 2006: Australasia, China, Iberia, Italia, Korea (Kiviniemi 2006).

Because IFC 2.0 had aggressively increased the scope of information supported by the standard, IFC 2x was primarily a stability release, which included considerable rework of some of the underlying technical architecture (Liebich 2010). The schedule for the IFC 2x release was 30 months, with work on the release being conducted from January 1998 to July 2000, the final version was published in October 2000. IFC 2x2 was released in May 2003 and was a release that brought with it considerable scope increase. 2D model space geometry, presentation, extension of the building service component breakdown, structural analysis structural detailing, support for building code checking and facility management (Liebich 2010). In 2005 the stable core of IFC2x obtained the ISO/PAS16739 status (ISO.org[2]).

During this time a significant push for IFC-based BIM was initiated in Finland in the form of the ProIT project, a national effort that ran between 2002 and 2005. ProIT was a broad joint project between public sector bodies and construction industry companies, coordinated by the Confederation of Finnish Construction Industries, with the goal to facilitate the use of product model data in the construction process. In addition to the important role of increasing market awareness and coordination on the topic by disseminating up-to-date information about BIM technology use in projects, modeling guidelines were developed for both architectural and structural design (ProIT 2004 & ProIT 2005). Furthermore the project signaled some of the first formal public sector interest in BIM and IFC, the project contributed directly to IFC standardization by developing an 'IFC Aspect Card Library', which provided pre-defined subsets of the IFC information model to support implementation of IFC data-exchange by having specific use-cases to base the exchange on (Karstila & Serén 2005). While the data-exchange use cases were primarily intended to support the modeling guidelines for the Finnish construction industry developed within the ProIT project, the work put into the development of the aspect card methodology was a direct contribution to facilitating implementation and use of the IFC standard and a more bottom-up minimalist approach to interoperability.

In summarizing some early lessons learned from deployment of IFC compatible software in three high-profile pilot projects, Baznajac (2002) evaluated the state of the standard from both a technical and methodological perspective. Among most notable findings was that the industry was largely unprepared to work on integrated projects, with workflows not leveraging the benefits of BIM, thus weakening the end-user demand for an open standard. Baznajac (2002) concluded that there were problems related to incompatible data and limitations for what data could be successfully transferred, but remained optimistic that these technical problems would be resolved within the near future by developing the IFC data model further and specifying limited views for data exchange, in addition to having dedicated modeling and data integration experts oversee population and exchange of data in projects. In a test of of IFC 2x interoperability for architectural domain data, Pazlar & Turk (2008) conducted IFC file-based exchange evaluations within and between three widely used IFC 2x certified software applications. Based on both visual and semantic analysis of the exchanged data the main result was that IFC-based exchange cannot be blindly trusted because of the loss of data between the exchanges. In a direct evaluation of the standard itself, Amor et al. (2007) conducted a meta-level analysis on the structure of the IFC data model and its development through version 1.5.0 to 2x3, resulting in an express for concern regarding unnecessary complexity in the model. Namely the number of associations and dependencies between classes, which reduction by refactoring techniques could make implementation maintenance easier. Amor et al. also tested the functionality of IFC translators available in commercial CAD systems, importing valid IFC files and directly exporting them back, concluding that the exported IFC files contained errors of varying severity, and indicating a need a address the issues in the IFC certification process and improving the accuracy of existing translators to retain semantic integrity on import and export.

3.4 2006-2011: The useful minimum

2006 saw a re-naming and re-branding of the IAI consortium to buildingSMART, a change which brought with it increased emphasis on business benefits of an interoperable integrated design and construction process. Central to this refresh was a reformulation of the consortia vision. As noted earlier the old vision was formulated as "To enable software interoperability in the AEC/FM industry." The new vision extends from simply technical aspects to emphasizing what interoperability enables for users and business *"Improving communication, productivity, delivery time, cost, and quality throughout the whole building life cycle"* (Stangeland 2009:1). This marked mostly a change in approach and methods, with little to no influence to the form of organization within the consortia.

In its overall standardization approach this time period marked a change from past by increased focus on minimalistic and bottom-up methods for of narrowing down IFC data exchanges into manageable, predictable, and implementable specifications. The general emergent climate is communicated well in Hietanen & Lehtinen's (2006) report "The useful minimum", where the concept of the useful minimum is defined as "*The minimum scope for data exchange, which makes IFC based exchange a better solution than any other available format.*" (Hietanen & Lehtinen's 2006:1). Reducing scope of information exchanges from dealing with any combinations of the whole IFC information model to limited well-supported and predictable workflows is seen as a gateway for the industry and implementers to increase their support for the standard, after which it would be easier to incrementally increase the number and scope of the supported exchanges when use of the standard increases.

A tangible outcome of the emergent minimalistic approach to standardization is the concept of Information Delivery Manuals (IDM), which specification was introduced as an official element of IFC standardization in 2007. IDMs are aimed to serve both technical implementation needs of software developers and provide role-based process workflows for end-users, supporting an integrated construction process. While buildingSMART could in theory release and endorse generic applied IDMs, buildingSMART's primary purpose is to provide a toolset and specification for how IDMs should be structured for the purpose of industry actors creating their own. An IDM is intended to be an integrated reference for processes and data required by BIM; it should specify where a processes fits and why it is relevant, who are the actors creating, consuming and benefitting from the information, what is the information, and how the information should be supported by software solutions (Wix, 2007). The IDM methodology and format was published as ISO/DIS 29481-1 in April 2010 (ISO.org[3]).

Another outcome of a minimalist standardization approach is the IFC Model View Definition Format (MVD), which definition goal was *"finding a useful balance between the wishes of users/customers and the possibilities of software developers, and documenting the outcome clearly."* (IAI 2006:2). Proposed by BLIS in early 2005, and introduced as an official element of IFC standardization in 2006, the MVDs narrow down the complete IFC model specification, documenting how data exchanges between different application types are applied; as such it is mostly something that is of direct benefit to implementers of IFC software. One software application can implement one or several MVDs depending on its domain scope. The MVD format is to a large extent a harmonization of the BLIS and ProIT efforts, which have both briefly been described earlier in this paper. How the both the IDMs and MVDs relate to each other and the wider context of the IFC information model is presented visually in figure 1.

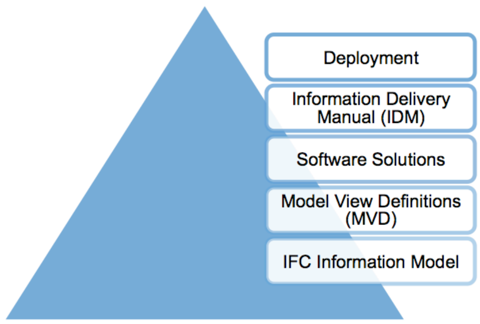

FIG. 1: Layers of the information exchange framework (based on Wix 2007:18)

The IFC information model is the foundation from which specific MVDs are defined. Software applications then implement these MVDs. IDMs provide documentation and guide the workflow of IFC enabled exchange, and are designed acknowledging the functionality of specific MVDs. These cross-referencing information exchange layers were designed to facilitate the deployment of IFC-supported interoperability.

In 2007 work was initiated on a new certification process for IFC implementations. The new processes was adopted by buildingSMART in 2010, dubbed "IFC Certification 2.0", and brought major improvements to the way certification was dealt with. Developed with MVDs in mind, emphasis is put on quality control of the IFC interfaces, having narrower more explicitly defined testing procedures than in the past (Groome 2010). In the new process software vendors can attain a two-year certificate for supporting already defined or newly defined MVDs based on the underlying IFC 2x3 information model. As such software is not universally certified 'IFC compatible', and rather gets certification for supporting specific MVDs. Where spreadsheets and extensive traveling was required in the old process, an advanced web-platform was developed to automate much of the process and provide centralized testing and documentation (Steinmann 2010).

In addition to the IDM and MVD concepts to extend the scope of standardization of IFC-based exchanges beyond the IFC information model, the International Framework for Dictionaries (IFD) effort was formally initiated within buildingSMART International around this same timeframe, in April 2008 (ifd-library.org). Referred to as the third pillar of IFC data exchange, together with IDM and MVD, IFD describes what is exchanged by providing a mechanism that allows the creation of dictionaries or ontologies, to connect information from existing databases to IFC information models (Bell & Bjorkhaug 2006). Initial work on a standard to fulfill similar purposes were initiated in 2006 as collaboration effort between the BARBi project in Norway and the Lexikon project in the Netherlands, which work was then continued within buildingSMART International (ifd-library.org).

4 DISCUSSION

4.1 IFC interoperability - a mix of structuralist and minimalist approaches

A summary of the IFC release timeline is shown in figure 2. buildingSMART currently aims for releasing major new versions of the standard with about three-year intervals, with the motivation that it strikes a balance between the need for stability to facilitate implementations, and responsiveness in incorporating new features to the standard (Liebich 2007).

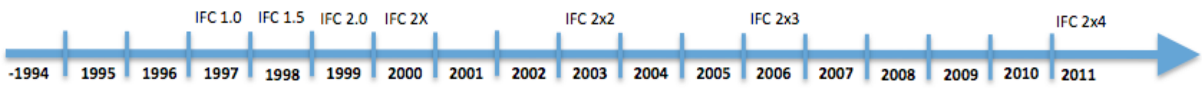

FIG. 2: IFC release timeline

The IFC standardization process has by and large been one of incremental development, where each release has expanded upon the foundation of previous releases without larger changes to completed work on the standard. This is common for technology development in general, but particularly so for technical standards, where revising earlier architectural design decisions causes compatibility issues. In the standards literature the phenomenon is referred to as path dependency (Liebowitz Margolis 1995). In the case of IFC, where the process has been going on for many years, it is interesting to see how early design decisions have, and still do, influence composition of the artifact and and development process over a decade later.

When IFC standardization was initiated the concepts of IDM, MVD, and IDF were not explicitly planned or defined, their need has emerged as the process went on. Initially the purpose was to create a definition framework for the core objects and concepts used in the AEC/FM industry. Generally one could state that it started with standardization of concept definitions which with time has expanded to include the processes of their use as well. The STEP standard has seen a similar evolution through the years starting with the initial split of the core model into Application Protocols with common universal resources, which for implementation viability were split into Application Interpreted Models and Application Reference Models. While harmonized core model definitions are the foundation for these implementable parts of the STEP standard, fragmentation into narrower data-exchange use-cases mitigates some of the ambitious original cross-domain interoperability goals of the STEP development. On this note Gielingh (2008) fundamentally questioned the viability of the underlying principles and concepts of STEP-originated open product data standards, including IFC. Gielingh argued that the poor performance of neutral product data exchange standards is due to inconsistent translations between the internal software data structures and the neutral format, ambiguity in how data structures can be defined while still conforming to standards, and the variations in domain scope between software applications. For IFC this problem has been solved with the new certification process, which is founded on certificating MVD support rather than only standards compliancy of translated objects and concepts. This approach should have very few drawbacks with regards to limiting what data-exchange use-cases can be done with the underlying IFC information model as implementers are allowed to define their own MVDs which specification is then made available for others to implement if they so choose.

While Behrman's (2002) notion that IFC standardization initially followed a structuralist approach gains support from the analysis in this paper, its rate of success in the industry should not be judged simply based on this finding. Such a perspective implicitly adopts a limited view on the dynamics involved in standardization. Suggesting that minimalist development approaches would be recommendable best practice for standardization purposes universally does not touch upon issues like openness in the process or product (Krechmer 2005), or necessary initial definition of concepts to be standardized, which are major reasons for having to adopt processes more in line with a structuralist approach. There are many more variables influencing the approach and outcome of standardization than polarizing structuralist vs. minimalist, like the degrees of technology and market maturity. In fact one could suggest that the IFC standard was originally intended to be a minimalist effort; a neutral data-exchange format developed outside of STEP, designed and used by members of its industry consortia consisting of several key software vendors. Choosing the pre-existing STEP file-format and EXPRESS as the modeling language should further support the initial minimalist intentions as existing work was chosen to be used as far as possible. Only after failing to find a viable minimal approach was a structuralist path taken regarding IFC – developing a complex model for mapping definitions of AEC/FM concepts and objects as well as their interrelations is a task which by design is arguably best suited for holistic structuralist development. While it generally holds true that releases of the IFC standard have usually first been published and only after the fact have implementations been attempted, this is more of a methodological development process issue than one stemming from lack of participation of software vendors in consortia activities as suggested by Behrman (2002). Software vendors make up a considerable share of the stakeholders who founded the consortia and they have been key funders, participants, and influencers within IAI and buildingSMART ever since. Regarding use of EXPRESS as the information modeling language as an obstacle for slow standardization, the development of an official XML representation of IFC, ifcXML, was started in 2001 and released later that same year. ifcXML provides XML language bindings to the IFC EXPRESS schema. However, because of the inherently different structures of the EXPRESS and XML modeling languages, translation of native IFC EXPRESS files to ifcXML result in needlessly large, lossy, and unoptimized files which do not play to the strengths of XML modeling (Behrman 2002). So simply translating between information modeling languages does not bring with it any instant fix to conceptual challenges in information modeling and interoperability, however, there are more people familiar with the widely adopted XML syntax than EXPRESS which might put an additional threshold for software developers to become involved in IFC development. However, the EXPRESS modeling language in itself does not strictly dictate how concepts are defined, nor has it become technically obsolete even though it is not in as widespread and general use as XML.

While not dedicatedly related to IT in the construction industry, interesting parallels to the IFC standard can be found in Henning's (2008) paper reviewing the rise and fall of the CORBA (Common Object Request Broker Architecture and Specification) middleware standard. Hennning noted that many of the problems with the standardization of CORBA were rooted in the 'design by committee' symptom of developing an anticipatory standard. Henning suggested the following to improve industry consortia standardization processes: standards consortia should have iron-cast rules in place to ensure that they standardize existing best practice, no standard should be approved without a reference implementation, no standard should be approved without having been used to implement a few projects of realistic complexity, and to create quality software, and the ability to say "no" is usually far more important than the ability to say "yes". One of Henning's more implicit messages is the cautious use of the word standard when referring to something still in development, as reliability and performance expectations are set high for anything proclaiming to be a standard. Henning split the analysis into technical issues and procedural issues, however, noting that *"[...] the technical problems are a symptom rather than a cause"* (Henning 2008:56). These points resonate well with the findings from Behrman (2002), but also to findings related to IFC standardization since then as described in this paper.

As discussed earlier, project-based funding from companies and governments around the world have been important resources in IFC standardization by directly and indirectly funding organizations and individuals active in IFC-related projects. However, the goals of tangent projects and the immediate optimal tasks of the standard development might not always be aligned. With the consortia operating on low fixed resources it can be speculated that it is unlikely that projects contributing to IFC development would get turned down, even if they do not comply with the immediate development priorities and vision of the consortia. For IFC one of the main problems with simply standardizing best practice rather than figuring out and developing something new is that BIM software has evolved at a rapid pace – making IFC standardization attempts at hitting a moving target. The IFC standard has been developed as it has been standardized, so called designing standardization, since no complete existing modules exist to simply pick and chose from. This type of anticipatory designing standardization is of high risk to fall into the trap of 'design by committee' if goal-orientation is not kept as a high priority (Purao et al. 2008). While it is hard to prepare and predict for the distant future, aligning 'time-to-standard' with 'time-to-market' goals has been shown to be of great importance for widespread adoption of standards (Gielingh, 2008). With development started early in the technological development cycle, one technological limitation which has emerged as computing has moved from local to networked is the lack of native model server support in the STEP architecture on which IFC is based. However, various software applications have been developed to remedy this increasingly important feature.

The purpose of this paper has been to review the IFC standardization process with particular emphasis on the different types of development approaches for reaching interoperability. It is suggested that both structuralist and minimalist development approaches have been used to complementary effect for different parts of the standard and during different phases of the process. Many interesting aspects of the effort have only been mentioned in brief, however, such underdeveloped discussions are hoped to spur future research interest for both technical and social research related to IFC standardization.

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